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Technical Analysis and Statistics from Long Term Helium Cryoplant Operation with Experimental Superconducting Magnets at CERN

J.-P. Dauvergne, D. Delikaris and F. Haug

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CERN
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D. Delikaris, J.-P. Dauvergne, F. Haug

CERN, CH-1211Geneva 23, Switzerland

CERN regularly uses a large number of liquid-helium cryoplants for cooling the superconducting magnets of large particle detectors. They are installed in the experimental areas of the electron-positron collider LEP and the proton (and heavy ion) accelerator SPS for the observation of high-energy interactions of elementary particles. The typical cold mass of a detector magnet ranges from 1 to 40 tons, and typical cryoplant cooling capacities are between 400 and 800W/4.5K entropy equivalent. Operation must be very flexible to meet the varying experimental requirements. We intend to present technical data of the system and statistics from over 180'000 running hours during the four years from 1992 to1995. Operation includes phases of cool-down, steady-state cooling, recovery after magnet quench or other incidents and warm-up of the superconducting magnets. Emphasis will be laid on the analysis of fault conditions, multiple interaction between perturbations and consequences for the users of liquid-helium supply interruption.

INTRODUCTION

CERN began using superconducting magnets at a very early stage (in the 1970s), integrating them into its various high-energy physics experimental detectors [1]. Most of these magnets are still in operation today, having been used by several physics experiments in succession. The cryogenic installations have been modified over the years to meet the needs of the various users of the magnets. Today, nine cryoplants are exclusively allocated to experimental superconducting magnets. The important parameters for cryogenics are the cold mass of the magnets, which can vary according to type from 1 to 40 tons, and their stored energy, which ranges from 0.6 to 140 MJoules. The total cryogenic power used is 5,200W at 4.5K (entropy equivalent). The cryoplant cooling capacity varies from 400 to 800W at 4.5K, entropy equivalent.

This paper summarises four years of cryogenic operation on all of CERN's experimental physics installations (except those used solely for the accelerators). It will be interesting to note the diversity and origin of incidents that led to stoppages in the production of liquid helium for users. It will be particularly interesting to analyse the data from stoppages directly linked to faults in the cryogenic equipment in order to gain a better understanding of the necessary improvements to the various systems when the new cryogenic installations are designed for future experiments using superconducting magnets [1].

SPECIFICATION OF THE CRYOGENIC SYSTEMS

Helium cryogenics are currently used by two types of physics experiment at CERN:

-The experiments installed on the LEP e^+e^- collider. Two of these (ALEPH and DELPHI) have a solenoid [2]. All the experiments (ALEPH, DELPHI, L3 and OPAL) have superconducting focusing magnets (low-ß) on either side of the beam interaction point [3]. The LEP cryogenic system is divided into two main parts: at the surface can be found the helium storage, compression and purification equipment, while in the underground experiment and accelerator chamber are located the cold boxes and the liquid helium storage and distribution systems.

-The fixed-target experiments, installed in the areas where the various SPS particle beams are extracted. For these experiments, the cryogenic equipment (helium gas storage, compression and central purification systems) are located in buildings adjacent to the experimental halls (North Area for experiments NA35/49.1, NA49.2, NA44, NA47, CMS/RD5 and West Area for OMEGA, the oldest of all the installations). The cold boxes and the liquid helium distribution systems are installed close to the magnets they supply.

All the cryogenic installations (except those of OMEGA) are entirely automated for the various operating phases of the superconducting magnets (draining, cooling, normal operation, reheating). From a central control room connected to the equipment by data networks, a team of five operators runs the installations during working hours. Outside normal working hours one operator is on stand-by duty, and in the event of a technical problem on the installations is directly alerted by an automatic paging signal, visible from the CERN Technical Control Room.

It may be noted that, with the exception of OMEGA which was built in 1972, most of the others were built at the end of the 1970s (for the SPS experiments) and 1980s (for the LEP experiments). From the cryogenic point of view, it is interesting to note the diversity of magnet cooling modes to which the "external" cryogenics have had to adapt each time on initial installation (circulation by liquid helium piston pumps, supercritical liquid helium, thermosyphon or saturated boiling liquid helium bath).

The first part of Table 1 shows the cryogenic installation's commissioning year and its rated power at 4.5K (entropy equivalent). It may be noted that all the cryogenic systems were first installed between 1971 and 1979 except those for the ALEPH and DELPHI experiments, which were commissioned in 1988.

TECHNICAL STATISTICS AND FAULT ANALYSIS FROM OPERATIONAL DATA

The second part of Table 1 shows two types of data for the periods of cryogenic operation from 1992 to 1995 inclusive. Firstly, the number of hours of operation of the installations by experiment and by year, followed by the number (and duration in hours) of accidental stoppages that led to an interruption in the supply of liquid helium to users.

The cryoplants allocated exclusively to physics experiments accumulated a total of 186,663 hours of operation in four years.

Table 1 also gives a more detailed view of the number and duration of liquid helium production stoppages, with a separate summary of the interruptions caused by a fault of cryogenic or other origin (essentially the related utilities). It should be noted that out of the 268 stoppages that occurred, only 50 were due to cryogenic equipment faults. More specifically, closer examination of the duration of those incidents which caused time to be lost by the accelerators and physics experiments reveals that 205 hours were associated with cryogenic equipment faults. Compared with the total number of 186,663 hours of operation, the breakdown rate was $3.13\ 10^{-3}$ for all stoppages and only $1.1\ 10^{-3}$ for interruptions caused by cryogenic faults. This low breakdown rate is essentially due to the rigorous annual preventive maintenance of the cryogenic installations. All maintenance procedures and spare parts management are controlled by computerised preventive and remedial maintenance systems.

In the context of these figures for breakdowns caused by the cryogenic systems, it is nonetheless important to point out two major incidents:

- On the oldest installation, OMEGA, a helium leak from an exchanger inside the cold box brought the experiment to a halt for four weeks while repairs were made. Coincidentally, the incident occurred only five days before the end of the physics run, and therefore only cost the experiment 120 lost hours. This one incident accounts for 120 of the 205 hours lost due to the cryogenic installations in four years of operation.
- On the L3 installation (low-ß), during the annual shutdown and after the maintenance of the 3.3kV electric cells, a phase inversion led to the destruction of the cryogenic system's helium compressor screw. Repairs took some three weeks but no lost hours were accounted for since the physics run had not yet begun.

As for the other incidents caused by cryogenic equipment faults, the major technical causes were: 24V power supply cut, fault in the control and regulating valves, fault in the electrical heating systems for helium, impurities in the helium cycle and a process software crash. The other interruptions in liquid helium production were essentially due to main electrical 3.3 kV and /or 220/380V power supply failures, to the compressor and turbine water-cooling system failures and finally to faulty signals from the users' safety systems.

It is important to remember that the magnets do not have sufficient liquid helium reserves to last for very long in the event of a cryoplant breakdown. Only a small number of installations such those at NA47 (reserves for 20 hours' operation) and at the low-ß quadrupoles (reserves for 2 hours' operation) can be switched to stand-by in the event of a fault in liquid helium production. Given the physical nature of a cryogenic system, an average utilities shutdown of 1.5 hours requires approximately 4 hours of cryogenic recovery to thermal equilibrium before the user can restore his magnet to operation. This demonstrates the importance of investment to boost the reliability of the cryogenic system utilities.

Although production stoppages, whatever their origin, cannot be totally eradicated, it is important to reduce their duration as far as possible. Moreover, a moderate liquid helium buffer could give users a certain autonomy and, more specifically, allow a normal discharge of the magnet current, pending repairs to the various systems.

The last point is that the various outside disturbances often cause fast current discharges (quenches). The cryogenic recovery after these quenches takes a long time and causes physics hours to be lost. The availability of the systems for physics experiments would be considerably increased by an improved selection system for triggering normal current discharges, where the cryogenics are not affected, more often than rapid discharges.

REFERENCES

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LEP Collider experiments														
ALEPH(including low-ß quadrupoles)	1988	800	6400	6480	5892	6624	25396	3(5)	1(1)	2(1)	2(3)	**8(10)**	9(25)	22(27)
DELPHI(including low-ß quadrupoles)	1988	800	6800	6480	6322	6696	26298	1(4)	2(4)	3(2)	2(7)	**8(17)**	7(12)	14(11)
OPAL low-ß quadrupoles	1976-79	400	6200	5760	6074	0*	18034	1(4)	1(1)	0(0)	0	**2(5)**	7(17)	12(16)
L3 low-ß quadrupoles	1976-79	400	5950	5760	5904	6144	23758	0(0)	2(17)	5(3)	2(3)	**9(23)**	6(15)	10(13)
SPS Fixed Target Experiments														
NA35/NA49.1	1976-79	400	2200	2160	1464	3168	8992	0(0)	0(0)	0(0)	2(5)	**2(5)**	0(0)	5(4)
NA49.2	1976-79	400	0	0	2184	3168	5352	0	0	1(1)	0(0)	**1(1)**	0(0)	0
NA44/45	1979-1991	400	2900	4320	3312	4152	14684	0(0)	0(0)	3(3)	2(1)	**5(4)**	0(0)	7(6)
NA47	1976-79	400	5700	7560	5544	5760	24564	1(6)	3(3)	2(1)	1(2)	**7(12)**	6(36)	5(5)
CMS-RD5 R&D	1976-79	400	3200	5400	2760	4152	15512	0(0)	0(0)	2(2)	0(0)	**2(2)**	0(0)	1(12)
OMEGA	1971	800	6200	5500	6362	6011	24073	2(3)	1(120)	0(0)	3(3)	**6(126)**	6(17)	8(4)
Total		**5200**	45550	49420	45818	45875	**186663**					**50(205)**		
			TOTAL NUMBER OF LOST HOURS =						Cryogenic Origin			**205**		

"*for the1995 run, the quadrupoles were connected to a 12kW cryogenic plant used for the cooling of the superconducting cavities in the LEP accelerator"